Aerospace Environmental Support Center

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IONOSPHERIC ELECTRON DENSITY PROFILE MODEL

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by

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and

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1. Preface.

Recent investigation of the effects of ionospheric retardation and refraction on satellite tracking radars has generated a need for a means to predict the errors and correct for them. This paper describes a project undertaken by 4th Weather Wing to produce a realistic electron density profile based upon parameters which can be forecast reasonably accurately. The authors wish to acknowledge the help provided them in this project. Lt Colonel Hansrote provided the impetus for producing such a model. Capt Jack Wrobel solved our initial problems of scale height by providing "Wrobel's Equation." MSgt Birch and TSgt Custer analyzed and evaluated the model against actual observations. Mrs. Green accomplished the manuscript typing. Thanks, also to Lt Bo Eross for his system analysis suggestions.

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II. Introduction.

The development of a computer program for predicting electron density profiles was prompted by the realization that ionospheric retardation and refraction produced errors in range and azimuth of satellite tracking radars. These errors are of the same order of magnitude as those produced by tropospheric effects when the UHF radars are operating above a few degrees elevation. Since the effects are rather small, it was assumed that a simple model from 100 km to 1000 km would be sufficient. However, as development work began, other requirements for electron density profiles became apparent. A three-dimensional ionosphere for HF ray tracing, which requires considerably more accuracy in the lower ionosphere, was requested. In addition, total electron content for correcting for Faraday rotation in some navigational satellites requires a model extending higher than 1000 km.

The program described in this report has been used routinely for about eight months to predict electron density profiles for the FPS-85 radar at Eglin AFB, Fla. Results are encouraging enough to warrant publication. It should be considered an interim report, however, as improvements are sure to be required as its accuracy is evaluated for different purposes.

III. Development.

The ionospheric electron density profile model presented in this paper consists of the sum of three Chapman layers (E, F1, and F2). Each layer is of the form

$$N_h = N_{max} \exp \quad a[1-Z-\exp(-Z)]$$

where $Z = (h-h_{max})/h_s$

N_h = electron density at height h

N_{max} = electron density at the peak of the Chapman layer h_{max}

h_s = scale height at the peak (except for the topside of the F2 region)

The value of the constant, a, depends upon whether electrons are lost by attachment or by recombination. While neither process is unique in any layer, a is assumed to be 0.5 for the E-layer and 1.0 for the F1 and F2 layers.

Electron densities in the topside ionosphere are controlled by complex motions rather than a production-loss balance and cannot be successfully described strictly by a Chapman layer. An effort was made to keep from over-complicating the model and still obtain the best topside profile. After some experimentation a fit was obtained by simply using the Chapman equation for the topside ionosphere, but computing the electron densities by using a variable scale height throughout the region.

The scale height profile is calculated from the equation

$$h_s = \frac{\log h}{2.186 \times 10^{-2}} - 203.447$$

This equation describes the scale height of a simple standard atmosphere and was derived by Capt J. Wrobel (private communication).

Critical frequencies for the E and F1 regions are determined from regression equations [1], [2].

$$f_oE = 0.9[(180 + 1.44R) \cos \chi]^{0.25}$$

$$f_oF1 = 1.26 f_oE + 0.5$$

where R = the twelve-month running mean sunspot number

χ = the solar zenith angle

When χ exceeds 90°, f_oE is set to 0.7 MHz. When χ exceeds 135°, f_oE is set to 0.3 MHz.

The F2 region critical frequency may be predicted from the ITS (ESSA) coefficients by predicting a sunspot number (R) [1]. It may also be predicted manually on a short-term basis by the Air Force Aerospace Environmental Support Center. For post analysis purposes, an observed value may be used.

The height of the peak of the E region is assumed to be 120 km. After some experimentation, the F1 peak was placed halfway between the E and F2 peaks.

The height of the F2 peak is calculated by using Shimazaki's equation [3]:

$$h_{max} = \frac{1490}{M} - 176$$

where the M(3000) factor, M, may be predicted in a manner similar to the prediction of foF2, or observed. Computations of h_{max} using M(3000) were found to be accurate within 20 km at mid latitudes. If a more accurate measure of h_{max} is available,

such as h_p F2, an artificial M(3000) may be calculated from the Shimazaki equation and used as an input into the computer program.

IV. Description of the Computer Program.

A copy of the computer program used to compute an electron density profile is listed in Appendix A. The program is written in IBM 7090 FORTRAN IV. There are three input options (all of which are concerned with the method of obtaining foF2 and M(3000)). Two output options are available, depending upon the representation of the profile required.

The program computes electron densities independently for each of three regions (E, F1 and F2). The base of the profile is 100 km and computations are made at 5 km increments to 1000 km. The three regions are added together to give the total electron density at each increment of altitude. Electron density is not permitted to decrease with altitude, but is held constant across "valleys" in the profile.

Total electron content in a one square meter cross section up to a given altitude is also computed. An initial electron content is established at 95 km, to represent the total content below 100 km. A calculation of plasma frequency is made from the electron density for each 5 km interval.

Input parameters are read from data cards. The first data card indicates output options (Table 1). The second data card contains information pertaining to the geographic location of the profile. The format of the card is the same for all input options (Table 2).

As previously mentioned, there are three input options which determine the method by which foF2 and M(3000) are introduced into the program. Data card number 3 contains information pertinent to the profile, including the input option variable IOPT. Table 3 lists the input parameters on the third data card and indicates which of them are used by the program under each of the three input options. If IOPT = 1, foF2 and M(3000) are computed from a card deck of ITS Prediction Coefficients. (Subroutines used to compute foF2 and M(3000) from ITS coefficients were extracted from a program published in [4].) If IOPT = 2, a long-term data tape containing sunspot dependent coefficients of foF2 and M(3000) is read to determine foF2 and M(3000). Finally, if IOPT = 3, foF2 and M(3000) are read explicitly from the data card.

TABLE 1

Card Column	Variable	Explanation
1	IPLOT	If IPLOT = 1, a profile of plasma frequency vs height is plotted. If IPLOT = 0, plot is suppressed.
2	IPNCH	If IPNCH = 1, the 17 most significant points depicting the profile are punched onto data cards. If IPNCH = 0, the punch routine is suppressed.

TABLE 2

Card Column	Variable	Explanation
1-6	CLAT	Latitude
7	NORS	Hemisphere (N, S)
8-13	CLONG	Longitude
14	IHEM	Hemisphere (E, W)
15-38	NAME	Name of Station

TABLE 3

Card Column	Variable	Required Under Option	Explanation
1-2	IYR	1, 2, 3	Year
3-4	MNTH1	1, 2, 3	Month
5-6	MNTH2	1, 2	Used if mean of two months coefficients are required.
7-8	IDA	3	Day
9-12	IBHR	1, 2, 3	Beginning time of set of consecutive profiles (GMT).
13-16	IEHR	1, 2, 3	Ending time of set of consecutive profiles (GMT).
17-18	INC	1, 2, 3	Increment of time step (hours).
19-21	JDAY	1, 2, 3	Julian Day
22	IOPT	1, 2, 3	Option
26-30	SSN	1, 2, 3	Sunspot Number
31-40	FOF2	3	foF2 (explicit) MHz and tenths
41-50	EM3000	3	M(3000) (explicit) hundredths
51-56	IVB	1, 2	Beginning of valid time (i.e., 10 May).
57-62	IVE	1, 2	Ending of valid time (i.e., 20 May).

NOTE: All numbers are integers except SSN, FOF2, and EM3000. These three are floating point, punched with a decimal point, anywhere in the field.

V. Description of the Computer Produced Profile.

Appendix 2 is a sample profile produced by computer. The profile is in four sections. The first section provides a summary of input data and pertinent information for each of the three regions. The second section is the profile itself, listing values of height, E-region density, F1-region density, F2-region density, total density, cumulative electron content, plasma frequency and scale height for each 5 km increment of the model. Output of the third section depends upon the value of the output option IPLOT (see Table 1), and plots a graph of plasma frequency vs height for the model. The fourth and final section depends upon the value of the output option IPNCH. If selected, the 17 most significant values of plasma frequency describing the profile are chosen objectively and written onto magnetic tape for punching onto data cards. In addition, a checklist of the points selected is printed.

VI. Evaluation of the Model.

An evaluation of this model was made by comparing with observed electron density profiles and with total electron content measurements.

Figures 1 to 8 show model monthly median profiles for Wallops Island, Va., during 1968, compared with the observed profiles available from World Data Center A, Boulder, Colorado. Excellent results are obtained during winter and at night. The July 1800Z (mid-day) is the worst case among several dozen such comparisons at various locations and times.

In Table 4, the total electron content calculated to 1000 km is compared with observations of total content from Bedford, Mass., to geostationary satellites, a path which passes through the F2 peak near Wallops Island. These observations, courtesy of Jack Klobuchar, Air Force Cambridge Research Laboratories, are converted to vertical incidence by assuming a cosine correction factor. As expected, the model is generally lower than the observations since it cuts off at 1000 km. It is interesting to note that in the summer daytime, when the model overestimates the bottomside content (Figure 6), it underestimates the total content. This implies that more electrons are present in the topside than the model predicts.

A third comparison is shown in Figure 9. Here, total content to 1000 km from the model is compared with the total content on near vertical incidence paths to synchronous satellites in the vicinity of Hawaii [5]. The shape of the diurnal curve is good and the results are again excellent at night but are underestimated at midday.

TABLE 4

TOTAL ELECTRON CONTENT

$(10^{-}\ M^{-2})$

WALLOPS ISLAND 1968

GMT	OBSERVED TEC	MODEL TO 1000 KM	PERCENT DIFFERENCE
January			
0100	1.2	1.0	-10
0500	.66	.56	-15
2000	4.1	3.5	-15
March			
0200	1.6	1.4	-13
0500	.98	.95	-3
1100	.65	.61	-6
1600	3.3	3.2	-3
2100	3.7	3.4	-8
May			
0300	1.5	1.4	-7
0700	.85	.93	+9
1200	1.4	1.2	-14
1600	2.3	2.0	-13
2200	2.7	2.1	-22
July			
0400	1.2	1.1	-8
0800	.62	.60	-3
1300	1.4	1.3	-7
1800	1.8	1.6	-11
2300	2.1	1.6	-24
September			
0100	1.4	1.4	0
0500	.91	.89	-2
1000	.42	.46	+10
1500	2.4	2.4	0
2000	2.9	2.7	-7
November			
0200	.75	.65	-13
0600	.55	.52	-5
1100	.39	.36	-8
1600	3.2	3.3	+3
2100	3.2	2.8	-13

VII. Summary and Conclusion.

The electron density profile model came about as an attempt to produce a reasonably simple method of predicting electron densities in the 100-1000 km range. This model should not be considered final, by any means, even for the current applications. The scale height profile should be improved to include diurnal and seasonal variations. The model should be extended from its upper limit of 1000 km to the plasmapause. Variations of electron density with geomagnetic activity should be included. Improved prediction or specification of any of the input parameters will, of course, improve the accuracy of the profile model. The height of the F2 maximum is probably the most important of these.

VIII. References.

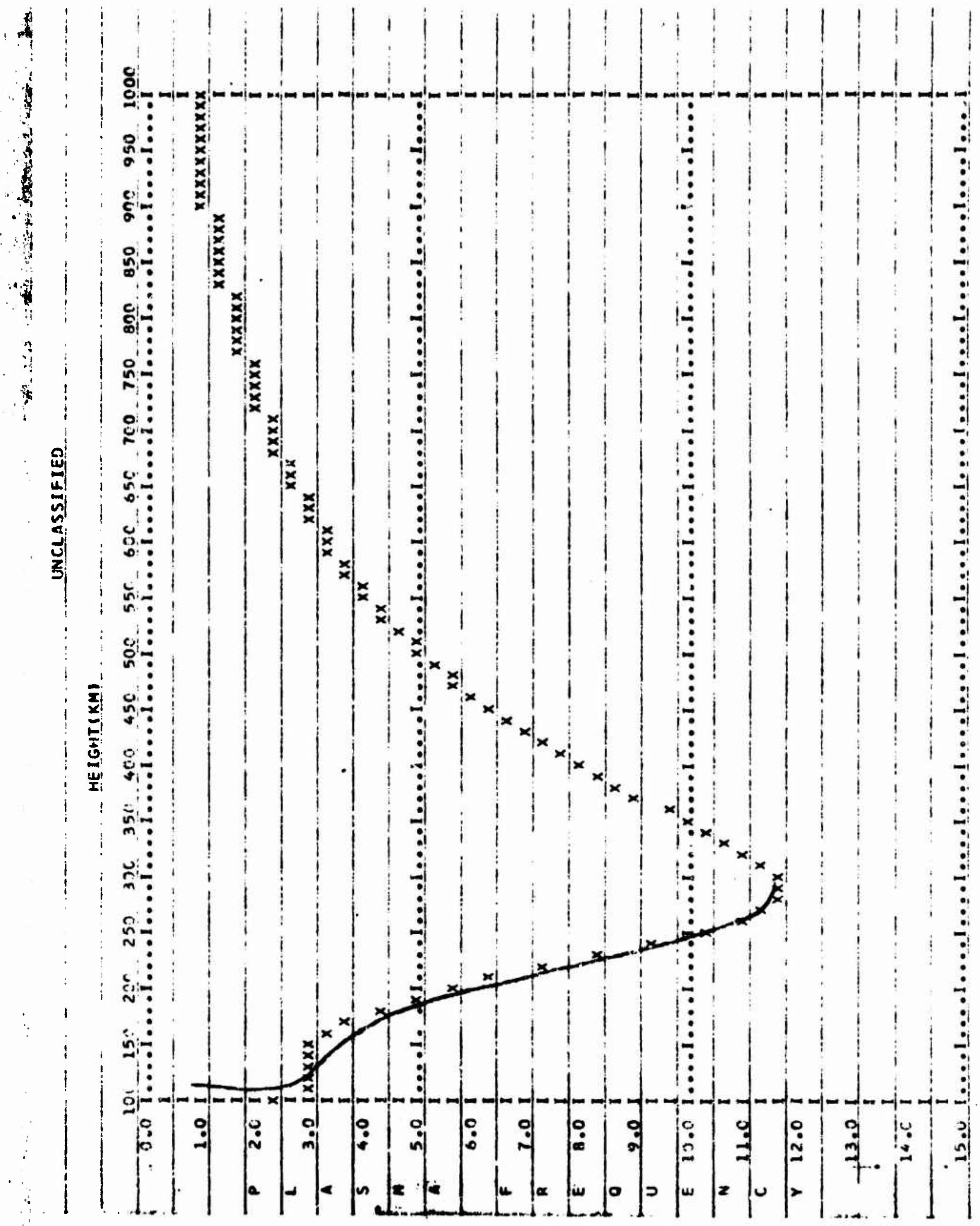
1. Barghausen, A. F., J. W. Finney, L. L. Proctor, and L. D. Shultz (1969), Predicting Long-Term Operational Parameters of High-Frequency Sky-Wave Telecommunications Systems, ESSA Technical Report ERL 110-ITS 78.

2. Haydon, G. W. and D. L. Lucas (1968), "Predicting Ionospheric Electron Density Profiles," Radio Science, Vol 3 (New Series) No 1, III.

3. Shimazaki, T. (1955), "World-Wide Daily Variations in the Height of the Maximum Electron Density of the Ionospheric F2 Layer," J. Radio Res. Labs, Japan, 2, 85-97.

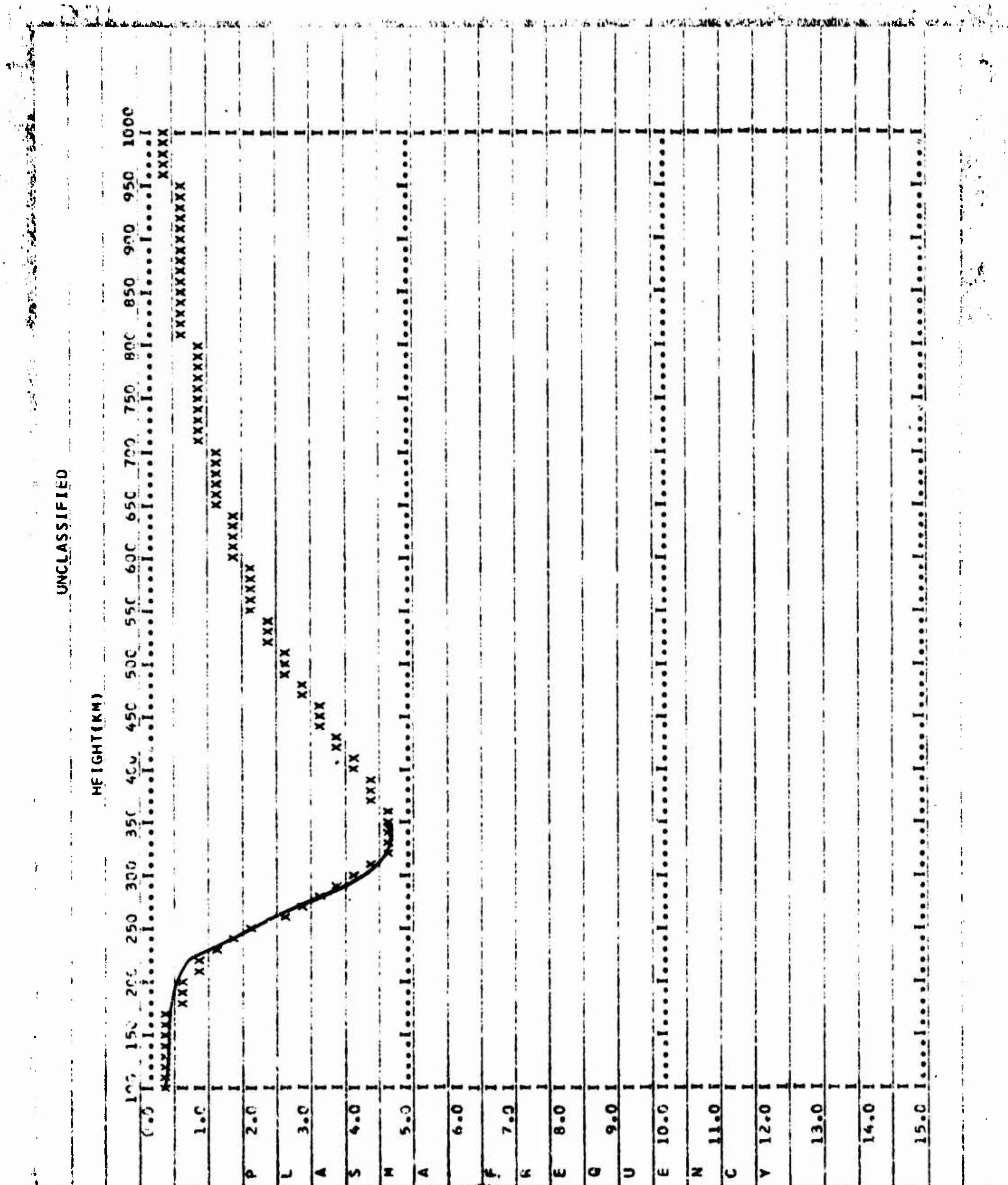
4. Jones, W. B., R. P. Graham, and M. Leftin (1969), Advances in Ionospheric Mapping by Numerical Methods, ESSA Technical Report ERL 107-ITS 75.

5. Yuen, P. C. and T. H. Roelofs, Atlas of Total Electron Content Plots, Vol 3, Radio Science Lab, University of Hawaii, Honolulu.



WALLOPS ISLAND MEDIAN JAN 68 0500Z

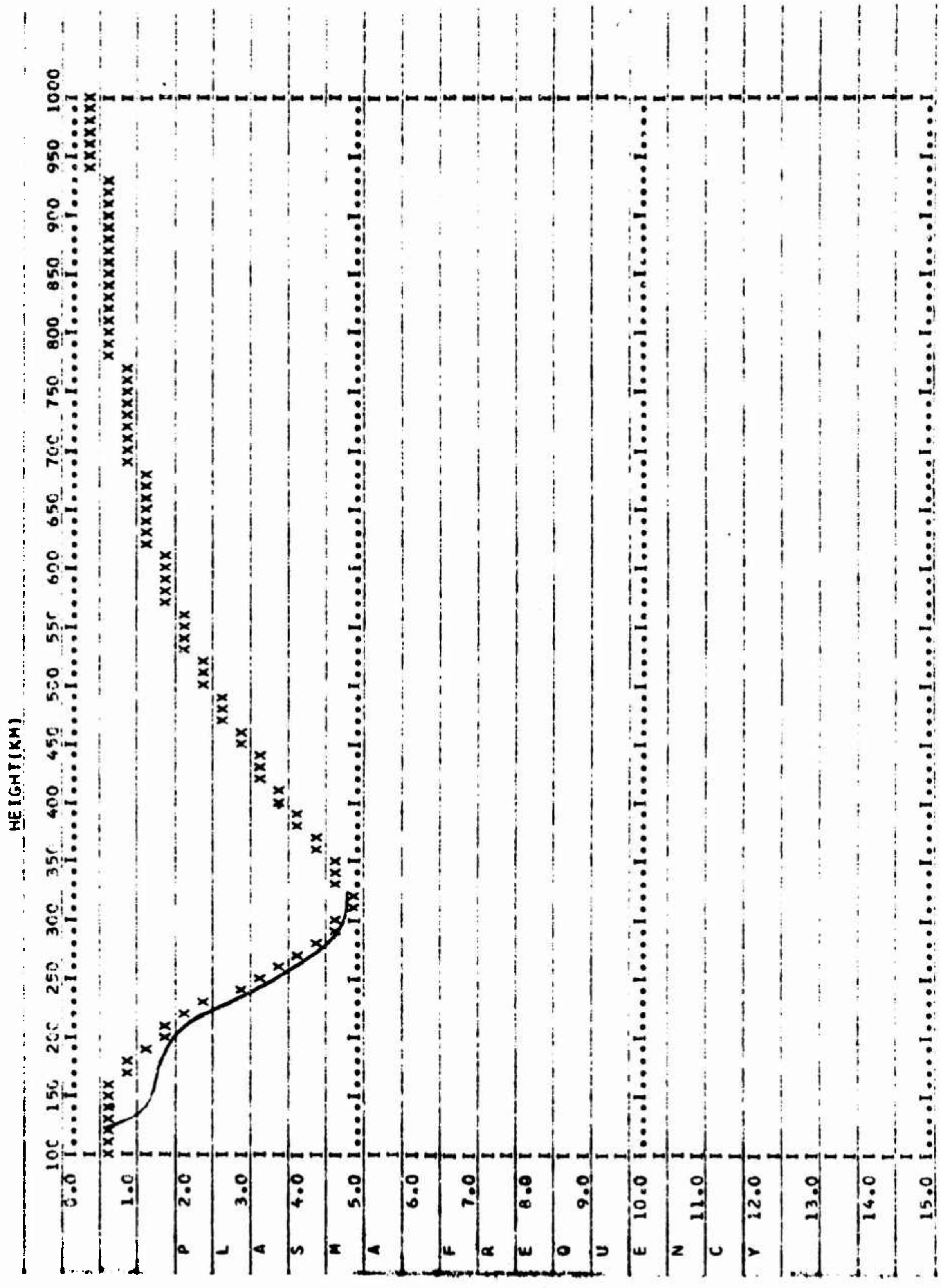
Figure 1



WALLOPS ISLAND MEDIAN JAN 68 2000Z

Figure 2

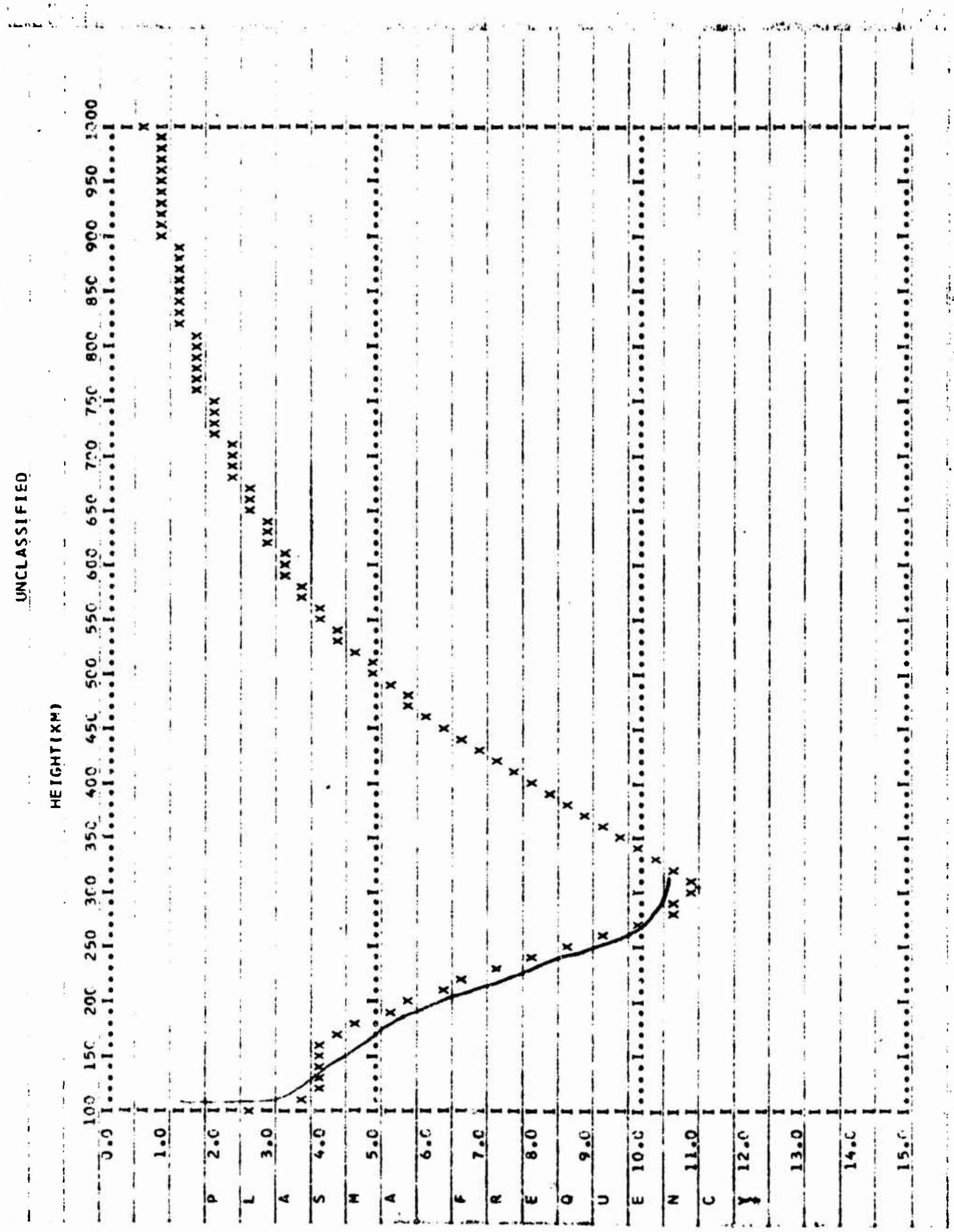
UNCLASSIFIED



WALLOPS ISLAND MEDIAN MAR 68, 1100Z

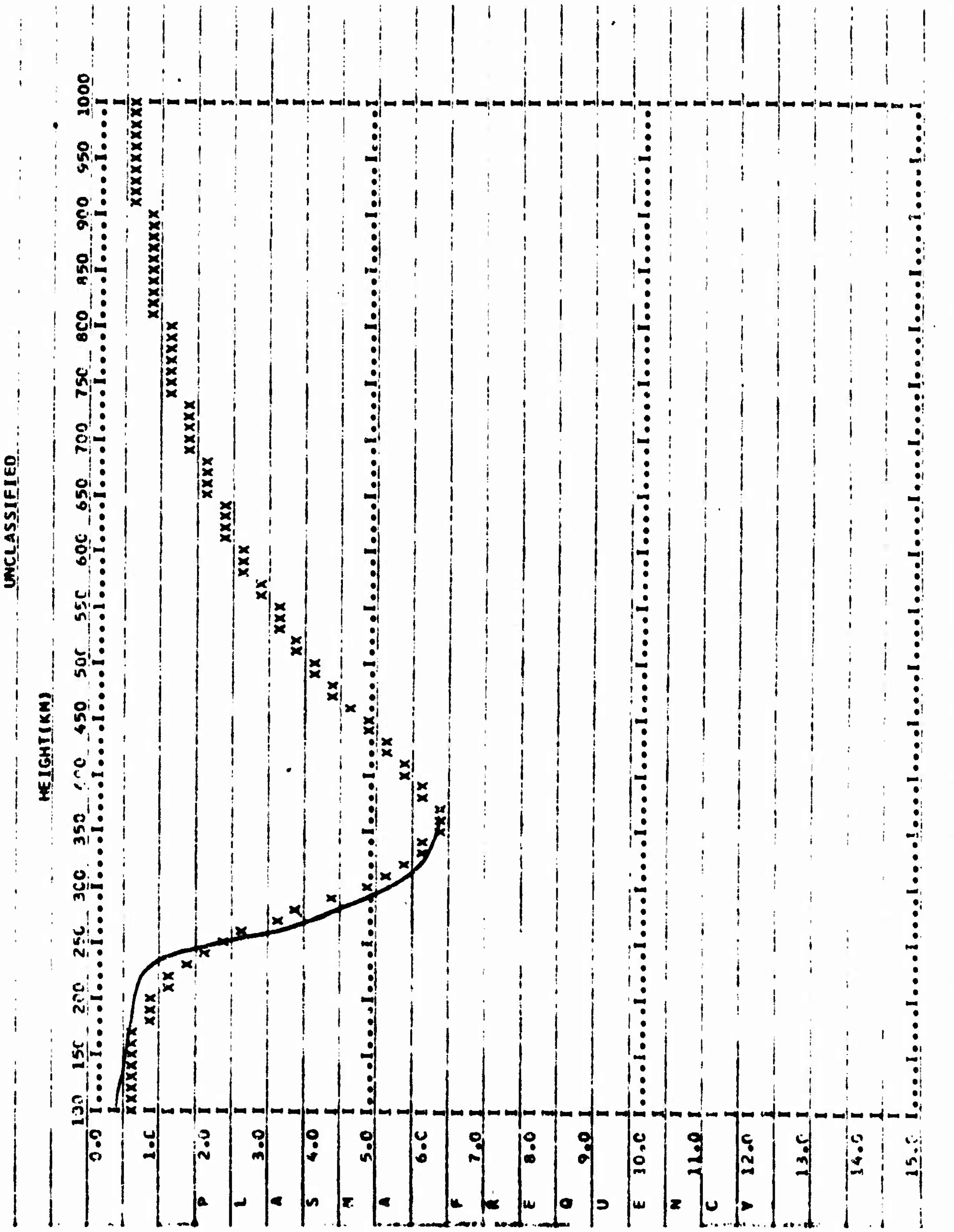
Figure 3

UNCLASSIFIED



WALLOPS ISLAND MEDIAN MAR 68 1600Z

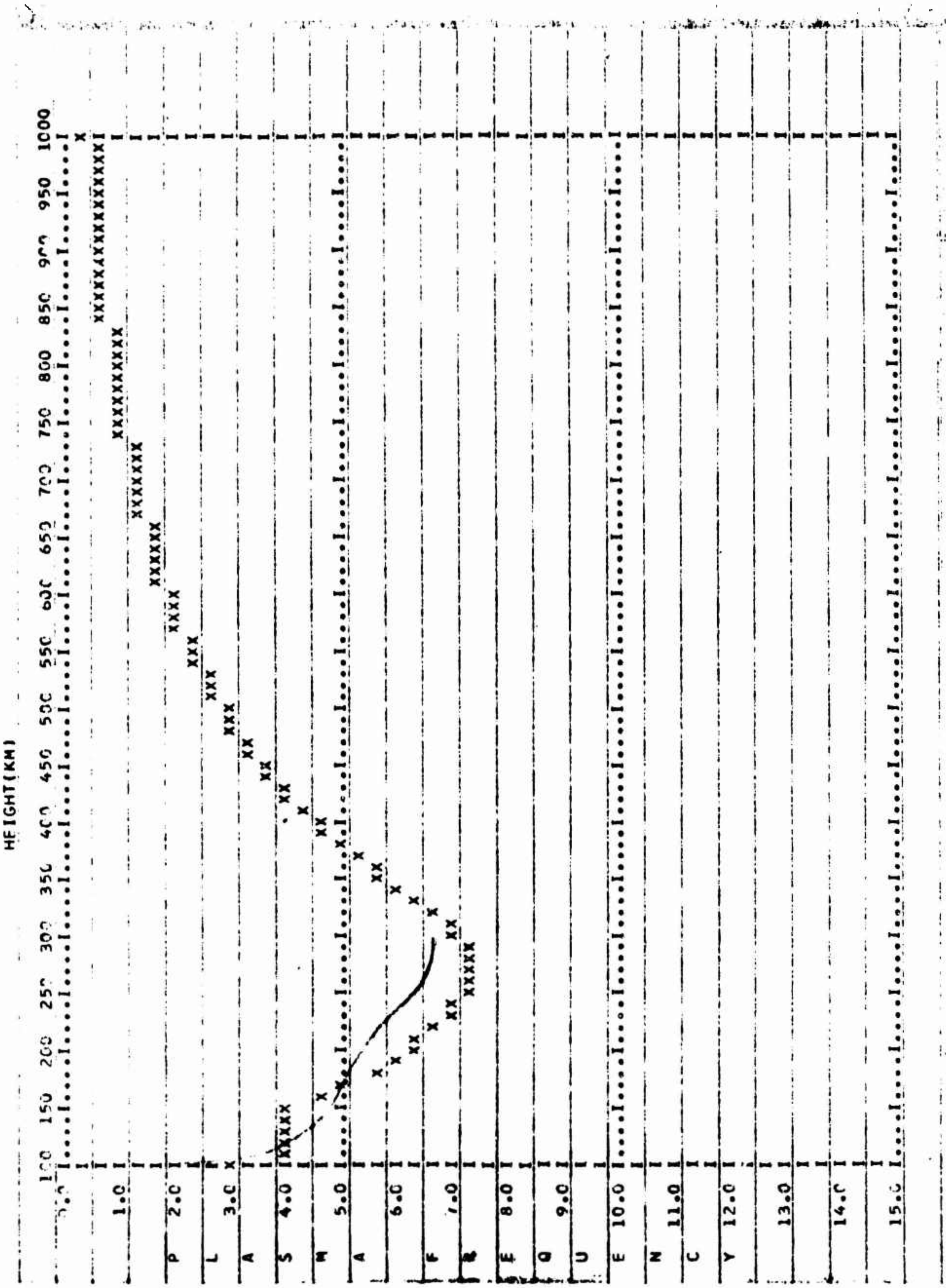
Figure 4



WALLOPS ISLAND MEDIAN JULY 68 0400Z

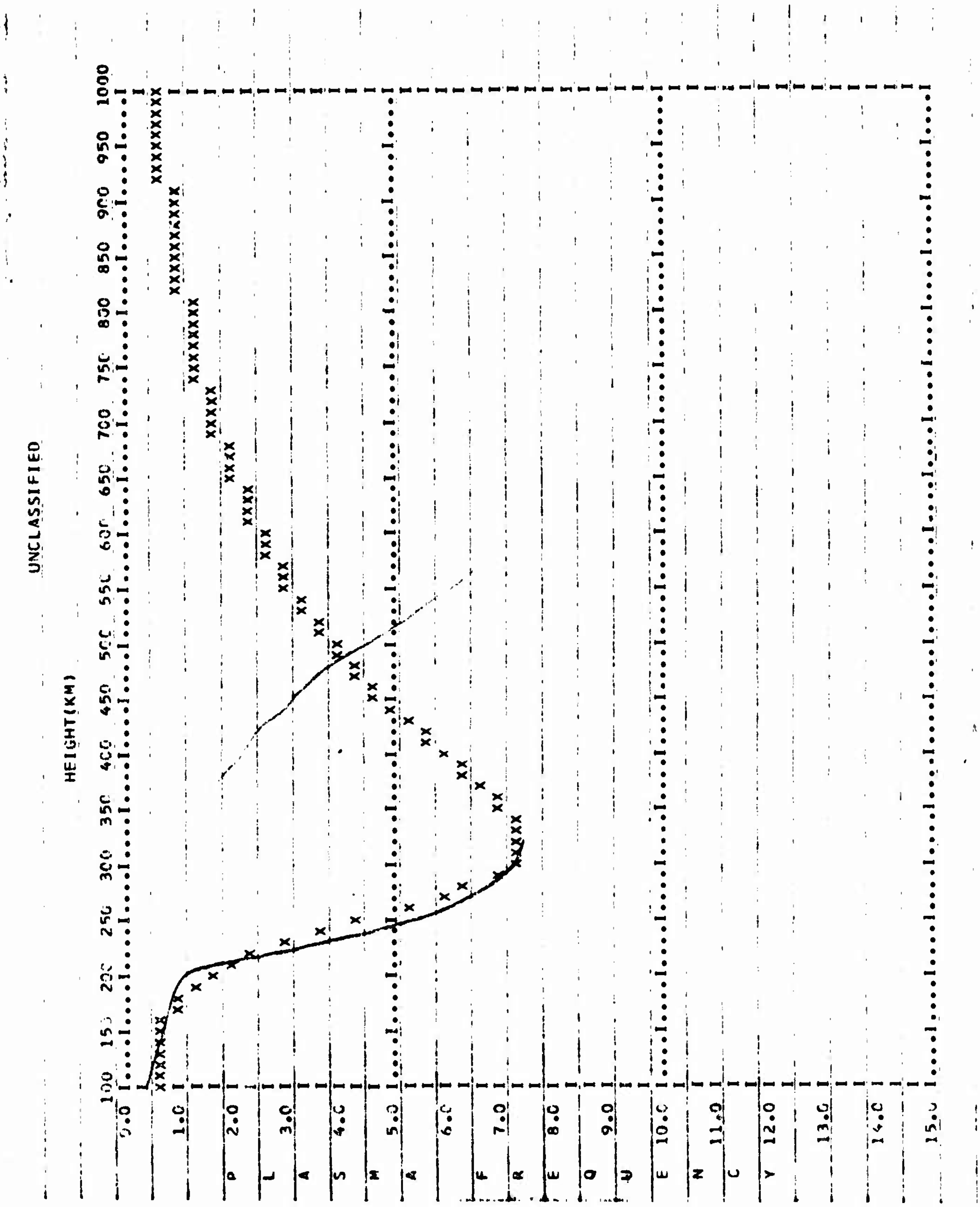
Figure 5

UNCLASSIFIED



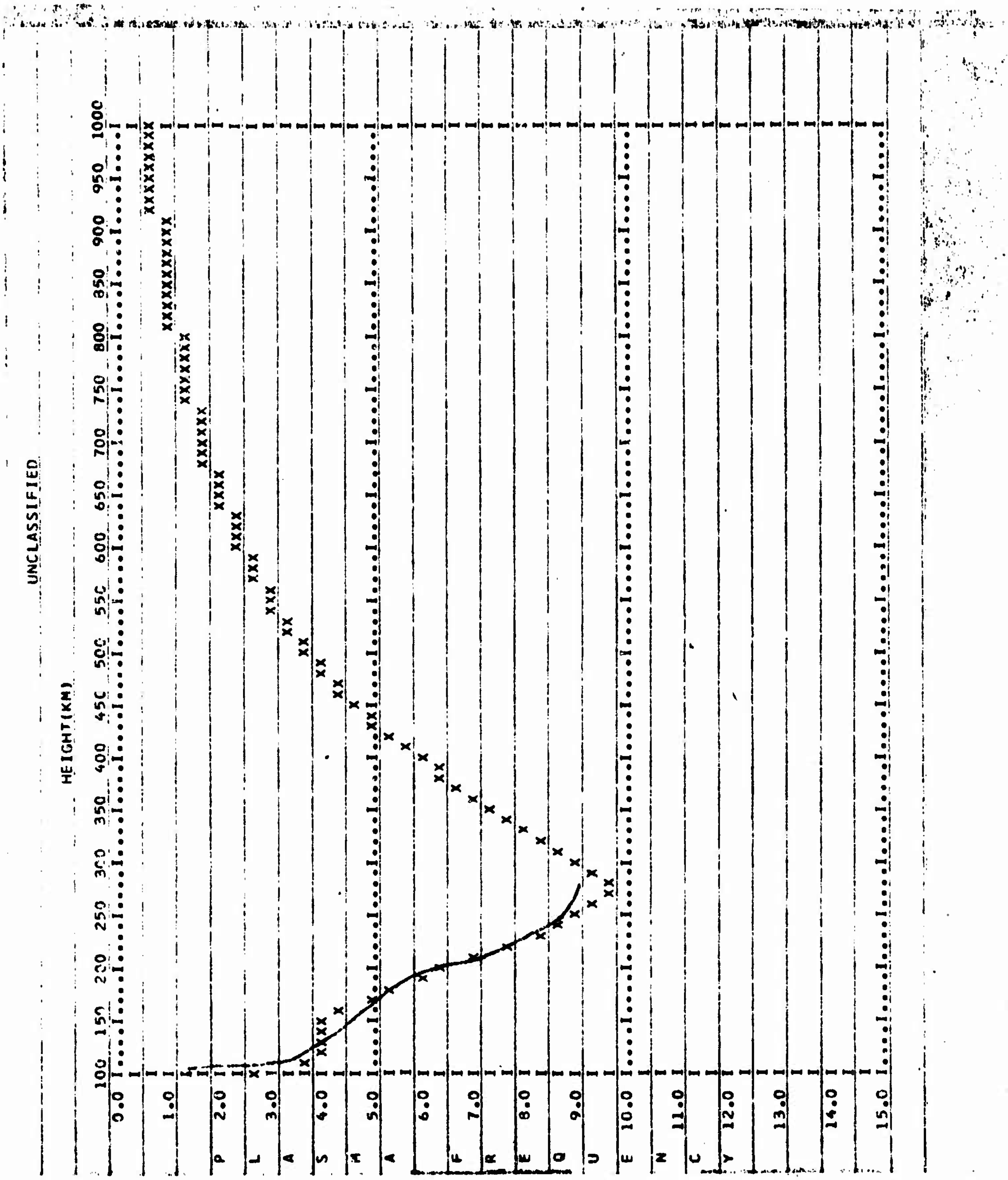
WALLOPS ISLAND MEDIAN JULY 68 1800Z

Figure 6



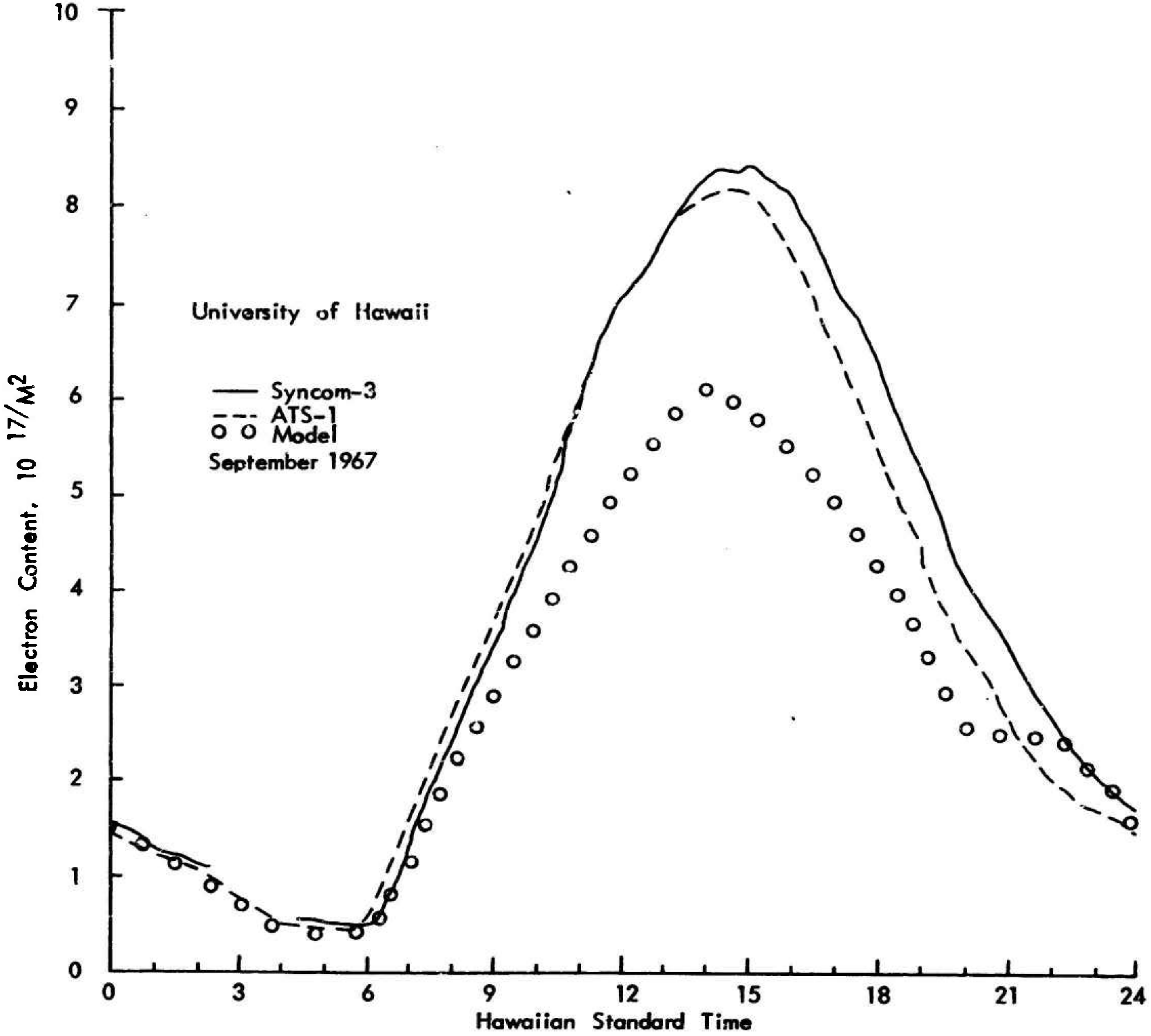
WALLOPS ISLAND MEDIAN SEP 68 0100Z

Figure 7



WALLOPS ISLAND MEDIAN SEP 68 1500Z

Figure 8



Electron Content, 10 17/M2
University of Hawaii
Syncom-3
ATS-1
Model
September 1967
Hawaiian Standard Time
0
1
2
3
4
5
6
7
8
9
10
0
3
6
9
12
15
18
21
24

FIGURE 9

Appendix A

Computer Program

"MODEL"

```
$IBFTC MODEL
      DIMENSION SCALE(182),IHGT(182)
      DIMENSION VAL(91),NAME(4),STOR(182)
      COMMON /B/ K(14),U(17,76),KX(14),UX(17,76),K1(14),KX1(14),
     1U1(17,76),UX1(17,76)
      DATA IE,IS/1HE,1HS/
C
C******  SET UP CONSTANTS FOR RADIAN CONVERSION  *******
C
      C180=3.1415927
      PI2=C180/2.0
      AK=C180/180.0
      BK=180.0/C180
      GLT=1.36135662
      GLG=1.22173030
      KARL=0
C
C*****  SCALE HEIGHT COMPUTATION (WROBEL-S EQUATION)  *****
C
      H=95.
      DO 10 I=1,182
      SCALE(I)=(ALOG(H)/2.186E-02)-203.447
      IHGT(I)=H
      IF(I.EQ.1) SCALE(I)=6.6
10    H=H+5.0
C
C******READ OUTPUT OPTIONS  ******
C
      READ (5,11) IPLOT,IPNCH
11    FORMAT (2I1)
C
C******READ LOCATION OF STATION  ******
C
999   READ (5,4) CLAT,NORS,CLONG,IHEM,(NAME(I),I=1,4)
4     FORMAT (2(F6.1,A1),4A6)
C
C******  CHECK FOR BLANK CARD (END OF ALL DATA)  ******
C
      IF(CLAT.EQ.0.0) GO TO  777
C
C******  CHECK FOR EASTERN OR SOUTHERN HEMISPHERE  ******
C
      IF(NORS.EQ.IS) CLAT=-1.*CLAT
      IF(IHEM.EQ.IE) CLONG=-1.0*CLONG
8000  READ (5,44) IYR,MNTH1,MNTH2,IDA,IBHR,IEHR,INC,JDAY,IOPT,SSN,FOF2,
     1EM3000,IVB,IVE
44    FORMAT (4I2,2I4,I2,I3,I1,3X,F5.1,2F10.5,2A6)
      IHR=IBHR
      INC=INC*100
C
C******  CHECK OPTION  1 = ITS COEFFICIENTS READ FROM CARDS
C                      2 = LONG TERM DATA TAPE
C                      3 = FOF2 AND M(3000) EXPLICIT  ********
C
```

```
      IF(IOPT.EQ.1.AND.KARD.EQ.0) GO TO 1
      IF(IOPT.EQ.1.AND.KARD.EQ.1) GO TO 34
      IF(IOPT.EQ.2) GO TO 2
      IF(IOPT.EQ.3) GO TO 3
      GO TO 33
C
C******  IOPT = 1, READ CARDS  ******
C
1     CALL READU(K,U)
      CALL READU(KX,UX)
      IF(MNTH2.GT.0) CALL READU(K1,U1)
      IF(MNTH2.GT.0) CALL READU(KX1,UX1)
      KARD=1
      GO TO 34
C
C******  IOPT = 2, READ LONG-TERM DATA TAPE  ******
C
2     CALL LTAPE(MNTH1,SSN,K,U,KX,UX)
      IF(MNTH2.GT.0) CALL LTAPE(MNTH2,SSP,K1,U1,KX1,UX1)
34    CONTINUE
800   CALL DOIT(CLAT,CLONG,IHR,FOF2,EM3000,MNTH1,MNTH2)
      GO TO 3
33    WRITE (6,333)
333   FORMAT (1H1,13HERROR IN IOPT)
      GO TO 777
3     CONTINUE
C
C******  IOPT = 3, BEGIN COMPUTATIONS  ******
C
C
C******  NOW HAVE FOF2 AND M3000 BY ONE OF THREE METHODS  ******
C
C******  CALCULATE SOLAR ZENITH ANGLE  ******
C
      IFRST=IHR/100
      SECND=IHR-IFRST*100
      SECND=SECND/60.
      GMT=FLOAT(IFRST)+SECND
      IF(GMT.EQ.0.0) GMT=24.
      D=JDAY
      SSP=-23.45*COS((D+10.)/365.*C180*2.)
      SSP=SSP*AK
      SSL=15.0*GMT-180.0
      Z=(SSL-CLONG)*AK
      COMP=SIN(CLAT*AK)*SIN(SSP)+COS(CLAT*AK)*COS(SSP)*COS(Z)
      COMP=ARCOS(COMP)
      COMP=ABS(COMP)
      RANG=COMP
      ZANG=COMP*BK+0.5
C
C         CALCULATE GEOMAGNETIC LATITUDE
C
```

```
      GAT=ARCOS(SIN(GLT)*SIN(CLAT*AK)+COS(GLT)*COS(CLAT*AK)
     1*COS(CLONG*AK-GLG))
      GLAT=(PI2-GAT)*BK
      R= SSN
C
C******   NOW HAVE NEEDED PARAMETERS FOR EQUATIONS   ******
C
C
C******   HEIGHT OF E-REGION SET TO 120 KM   ******
C
      HE=120.0
C
C******   COMPUTE SCALE HEIGHT OF  E-REGION   ******
C
      TE=(ALOG(HE)/2.186E-02)-203.447
C
C******   COMPUTE FOE   ******
C
      PART=0.9*((180.0+1.44*R)*COS(RANG))
      IF(PART.GE.0.) FOE=PART**0.25
      IF(PART.LT.0.) FOE=0.7
C
C******   IF SOLAR ZENITH ANGLE GREATER THAN 130 DEG, FOE SET TO 0.3 ****
C
      IF(ZANG.GE.90.0) FOE=0.7
C
C******   IF SOLAR ZENITH ANGLE GREATER THAN 90 DEG, FOE SET TO 0.7  ****
C
      IF(ZANG.GE.130.) FOE=0.3
C
C******   COMPUTE FOF1   ******
C
      FOF1=1.26*FOE+0.5
C
C****** COMPUTE MAX DENSITY OF E-REGION   ******
C
      ENE=1.24E04*(FOE)**2
C
C******   COMPUTE MAX DENSITY OF F1-REGION   ******
C
      FNMAX=1.24E04*(FOF1)**2
C
C******   COMPUTE MAX DENSITY OF F2-REGION   ******
C
      ENMAX=1.24E04*(FOF2)**2
C
C******   COMPUTE HEIGHT OF MAX DENSITY (SHIMAZAKI EQUATION)   *****
C
      HMAX=1490.0/EM3000-176.0
C
C******   COMPUTE SCALE HEIGHT OF F2-REGION   ******
C
      TF=(ALOG(HMAX)/2.186E-02)-203.447
```

```
C
C******  HEIGHT OF F1-REGION SET TO MIDPOINT OF E- AND F2-REGIONS  *****
C
      HMAX1=(HMAX+120.)/2.
C
C******  COMPUTE SCALE HEIGHT OF F1-REGION  ******
C
      TF1=(ALOG(HMAX1)/2.186E-02)-203.447
      IF(IOPT.LT.3) WRITE (6,990) IVB,IVE,IYR,IHR
      IF(IOPT.EQ.3) WRITE (6,99) IYR,MNTH1,IDA,IHR
C
C******  OUTPUT SECTION  ******
C
C
C******  WRITE HEADING FOR SUMMARY PAGE  ******
C
990   FORMAT (1H1,26HIONOSPHERIC PROFILE VALID ,A6,2X,A6,2X,I2,I5,1HZ)
99    FORMAT (1H1,24HIONOSPHERIC PROFILE FOR ,3I3,I5,1HZ)
      WRITE (6,100) CLAT,NORS,CLONG,IHEM,(NAME(I),I=1,4)
100   FORMAT (1H0,17HSTATION LOCATION ,2(F6.1,A1)//15X,4A6)
      IF(IOPT.EQ.1) WRITE (6,1000)
      IF(IOPT.EQ.2) WRITE (6,1001)
1001  FORMAT (1H0,43HTHIS PROFILE BASED UPON LONG-TERM DATA TAPE)
1000  FORMAT (1H0,7X, 40HTHIS PROFILE BASED UPON ITS COEFFICIENTS)
      WRITE (6,101) FOF2,EM3000,FOE,FOF1
101   FORMAT (1H0,7HFOF2 = ,F5.2,10X,8HM3000 = ,F5.2,10X,6HFOE = ,F7.2,
     110X,7HFOF1 = ,F7.2)
      WRITE (6,102) GLAT,ZANG,R
102   FORMAT (1H0,23HGEOMAGNETIC LATITUDE = ,F7.2,5X,
     121HSOLAR ZENITH ANGLE = ,F7.2//1X,17HSUNSPOT NUMBER = ,F5.0)
      WRITE (6,103) TE,HE,ENE
103   FORMAT (1H0,19HVALUES FOR E-REGION//
     15X,15HSCALE  HEIGHT =,F7.2,3H KM/
     25X,9HHEIGHT = ,F7.2,3H KM/
     35X,10HDENSITY = ,F8.0,13H ELECTRONS/CC)
      WRITE (6,1040) TF1,HMAX1,FNMAX
1040  FORMAT (1H0,20HVALUES FOR F1-REGION//
     15X,15HSCALE  HEIGHT =,F7.2,3H KM/
     25X,9HHEIGHT = ,F7.2,3H KM/
     35X,10HDENSITY = ,F8.0,13H ELECTRONS/CC)
      WRITE (6,104) TF,HMAX,ENMAX
104   FORMAT (1H0,20HVALUES FOR F2-REGION//
     15X,15HSCALE  HEIGHT =,F7.2,3H KM/
     25X,9HHEIGHT = ,F7.2,3H KM/
     35X,10HDENSITY = ,F8.0,13H ELECTRONS/CC)
C******  WRITE HEADING FOR PROFILE PAGE  ******
      WRITE (6,201)
201   FORMAT (1H1,10X,24HELECTRON DENSITY PROFILE//5X,2HKM,5X,
     18HE-REGION,5X,9HF1-REGION,5X,9HF2-REGION,7X,5HTOTAL,7X,
     210HCUMULATIVE,5X,16HPLASMA FREQUENCY,5X,5HSCALE)
      ENP1=0.
      ENSAV=0.
```

```
C
C******  COMPUTE AND PRINT VALUES FOR EACH 5 KM LEVEL  ******
C
      H=95.
      DO 200 I=1,182
      J=I/2
      FZE=(H-HMAX1)/TF1
      EZE=(H-HE)/TE
C
C******  ELECTRON DENSITIES COMPUTED FOR F2-REGION BASED ON A
C******       CONSTANT SCALE HEIGHT IF BELOW THE F2-PEAK AND
C******       ON A VARIABLE SCALE HEIGHT IF ABOVE THE F2-PEAK  ******
C
      IF(H.GT.HMAX) ZEE=(H-HMAX)/SCALE(I)
      IF(H.LE.HMAX) ZEE=(H-HMAX)/TF
      EE=ENE   *EXP(0.5*(1.0-EZE-EXP(-1.0*EZE)))
      EN=ENMAX*EXP     (1.0-ZEE-EXP(-1.0*ZEE))
      FN=FNMAX*EXP     (1.0-FZE-EXP(-1.0*FZE))
      ENP=EN+EE+FN
      IF(H.GT.HE.AND.H.LT.HMAX1.AND.ENP.LT.ENE) ENP=ENE
      IF(H.GT.HMAX1.AND.H.LT.HMAX.AND.ENP.LT.FNMAX) ENP=FNMAX
      IF(ENP.LT.ENP1.AND.H.LT.HMAX) ENP=ENP1
      ENP1=ENP
      PLAS=8.97E-03*SQRT(ENP)
      STOR(I)=PLAS
      IF(MOD(I,2).EQ.0) VAL(J)=PLAS
      ENSAV=ENSAV+ENP*5.0EC9
      IF(I.EQ.1) GO TO 200
      IH=H
      WRITE (6,202) IH,EE,FN,EN,ENP,ENSAV,PLAS,SCALE(I)
202   FORMAT (3X,I4,1X,4(4X,F9.0),5X,1PE16.8,6X,0PF7.2,7X,F7.2)
200   H=H+5.0
C
C******  CALL PLOT ROUTINE IF REQUESTED  ******
C
      IF(IPLOT.GT.0) CALL PLOT(VAL)
C
C******  CALL PUNCH ROUTINE IF REQUESTED  ******
C
      IF(IPNCH.GT.0) CALL SIG(STOR,IHGT,IVB,IVE,IVR,IHR)
C
C******  IF IOPT EQUALS 3, ONLY ONE STATION ANALYZED PER FOF2 AND M(3000

      IF(IOPT.EQ.3) GO TO 999
C
C******  INCREMENT HOUR  ******
C
      IHR=IHR+INC
      IF(IHR.GT.IEHR) GO TO 999
      GO TO 800
C
C******  EXIT AND TERMINATE RUN  ******
C
777   CONTINUE
      ENDFILE 9
      REWIND 9
      STOP
      END
```

```
$IBFTC CURVE
      SUBROUTINE PLOT(VAL)
      INTEGER GRID(46,91),ABSC(46),FREQ(46)
      INTEGER EYE,BLANK,DOT,DASH,EX
      REAL VAL(91)
      DATA EYE,BLANK,DOT,DASH,EX/1HI,1H ,1H.,1H-,1HX/
      DATA(ABSC(I),I=1,46)/1H ,1H ,1H ,1H ,1H ,1H ,1HP,1H ,1HL,1H ,
     11HA,1H ,1HS,1H ,1HM,1H ,1HA,1H ,1H ,1H ,1HF,1H ,1HR,1H ,1HE,
     21H ,1HQ,1H ,1HU,1H ,1HE,1H ,1HN,1H ,1HC,1H ,1HY,1H ,1H ,1H ,1H ,
     31H ,1H ,1H ,1H ,1H /
      DATA(FREQ(I),I=1,46)/4H 0.0,4H    ,4H    ,4H 1.0,4H    ,4H    ,
     14H 2.0,4H    ,4H    ,4H 3.0,4H    ,4H    ,4H 4.0,4H    ,4H    ,
     24H 5.0,4H    ,4H    ,4H 6.0,4H    ,4H    ,4H 7.0,4H    ,4H    ,
     34H 8.0,4H    ,4H    ,4H 9.0,4H    ,4H    ,4H10.0,4H    ,4H    ,
     44H11.0,4H    ,4H    ,4H12.0,4H    ,4H    ,4H13.0,4H    ,4H    ,
     54H14.0,4H    ,4H    ,4H15.0/
      DO 200 I=1,46
      DO 200 J=1,91
      GRID(I,J)=BLANK
      IF(I.EQ.1) GRID(I,J)=DOT
      IF(I.EQ.1.AND.MOD(J,5).EQ.1) GRID(I,J)=EYE
      IF(I.EQ.16) GRID(I,J)=DOT
      IF(I.EQ.16.AND.MOD(J,5).EQ.1) GRID(I,J)=EYE
      IF(I.EQ.31) GRID(I, J)=DOT
      IF(I.EQ.31.AND.MOD(J,5).EQ.1) GRID(I,J)=EYE
      IF(I.EQ.46) GRID(I, J)=DOT
      IF(I.EQ.46.AND.MOD(J,5).EQ.1) GRID(I,J)=EYE
  200 CONTINUE
      DO 300 I=1,46
      GRID(I,1)=EYE
      GRID(I,91)=EYE
  300 CONTINUE
      DO 10 I=1,91
      LOC=3.0*VAL(I)+1.6
   10 GRID(LOC,I)=EX
      WRITE (6,50)
   50 FORMAT (1H1,40X,10HHEIGHT(KM))
      WRITE (6,51)
   51 FORMAT(1H0,11X,3H100,2X,3H150,2X,3H200,2X,3H250,2X,3H300,2X,
     13H350,2X,3H400,2X,3H450,2X,3H500,2X,3H550,2X,3H600,2X,3H650,2X,
     23H700,2X,3H750,2X,3H800,2X,3H850,2X,3H900,2X,3H950,2X,4H1000)
      DO 49 I=1,46
      WRITE (6,30) ABSC(I),FREQ(I),(GRID(I,J),J=1,91)
   30 FORMAT (5X,A1,2X,A4,1X,91A1)
   49 CONTINUE
      RETURN
      END
```

```
$IBFTC SIGNIF
      SUBROUTINE SIG(STOR,IHGT,IVB,IVE,IYR,IHR)
      DIMENSION STOR(182),IHGT(182),PLASQ(17)
      INTEGER HEIT(17)
      HEIT(1)=IHGT(2)
      HEIT(2)=IHGT(6)
      HEIT(15)=IHGT(182)
      HEIT(16)=IHGT(22)
      PLASQ(16)=STOR(22)
      HEIT(17)=IHGT(32)
      PLASQ(1)=STOR(2)
      PLASQ(17)=STOR(32)
      PLASQ(2)=STOR(6)
      PLASQ(15)=STOR(182)
      DO 1 I=1,181
      IF(STOR(I).EQ.STOR(I+1)) GO TO 4
1     CONTINUE
      HEIT(3)=IHGT(12)
      PLASQ(3)=STOR(12)
      K=12
      GO TO 5
4     HEIT(3)=IHGT(I)
      PLASQ(3)=STOR(I)
      K=I
5     DO 6 I=K,181
      IF(STOR(I+1).NE.STOR(K)) GO TO 7
6     CONTINUE
      HEIT(4)=IHGT(22)
      PLASQ(4)=STOR(22)
      K=22
      GO TO 8
7     HEIT(4)=IHGT(I)
      PLASQ(4)=STOR(I)
      K=I
8     DO 9 I=K,181
      IF(STOR(I).LT.STOR(I+1)) GO TO 9
      HEIT(7)=IHGT(I)
      PLASQ(7)=STOR(I)
      GO TO 10
9     CONTINUE
10    K=I-5
      L=I-10
      LL=I+5
      HEIT(8)=IHGT(LL)
      HEIT(6)=IHGT(K)
      HEIT(5)=IHGT(L)
      PLASQ(8)=STOR(LL)
      PLASQ(6)=STOR(K)
      PLASQ(5)=STOR(L)
      HEIT(9)=IHGT(52)
```

```
      PLASQ(9)=STOR(52)
      K=62
      IF(HEIT(9).GT.370) K=72
      HEIT(10)=IHGT(K)
      PLASQ(10)=STOR(K)
      HEIT(11)=IHGT(82)
      PLASQ(11)=STOR(82)
      HEIT(12)=IHGT(102)
      PLASQ(12)=STOR(102)
      HEIT(13)=IHGT(132)
      PLASQ(13)=STOR(132)
      HEIT(14)=IHGT(162)
      PLASQ(14)=STOR(162)
15    DO 100 I=2,17
      IF(HEIT(I).GE.HEIT(I-1)) GO TO 100
101   ITEMP=HEIT(I)
      HEIT(I)=HEIT(I-1)
      HEIT(I-1)=ITEMP
      TEMP=PLASQ(I)
      PLASQ(I)=PLASQ(I-1)
      PLASQ(I-1)=TEMP
      GO TO 15
100   CONTINUE
      IHR1=IHR-70
      IF(IHR1.LT.0) IHR1=2330
      IHR2=IHR+30
      IHR1=IHR1+10000
      WRITE (9,99) IVB,IYR,IVE,IYR,IHR1,IHR2
      WRITE (6,98) IVB,IYR,IVE,IYR,IHR1,IHR2
99    FORMAT (6HVALID ,A6,I3,3H - ,A6,I3,1X,I4,5HZ TO ,I4,
     132HZ  REMOVE THIS CARD BEFORE USING)
98    FORMAT (1H1,26HIONOSPHERIC PROFILE VALID ,A6,I3,3H - ,A6,I3,1X,I4,
     15HZ TO ,I4,1HZ)
      DO 200 I=1,17
      WRITE (6,97) HEIT(I),PLASQ(I)
      WRITE (9,96) HEIT(I),PLASQ(I)
200   CONTINUE
97    FORMAT (1X,4HIONO,12X,I4,F12.2)
96    FORMAT (4HIONO,12X,I4,F12.2)
      RETURN
       END
```

Appendix B

Sample Computer Output

IONOSPHERIC PROFILE VALID 23 MAY 07 JUN 70 1900Z

STATION LOCATION 24.0N 86.0W

EGLIN RANGE

THIS PROFILE BASED UPON ITS COEFFICIENTS

FOF2 = 9.25 M3000 = 2.76 FOE = 4.04 FOF1 = 5.59

GEOMAGNETIC LATITUDE = 35.48 SOLAR ZENITH ANGLE = 18.11

SUNSPOT NUMBER = 90.

VALUES FOR E-REGION

SCALE HEIGHT = 15.56 KM
HEIGHT = 120.00 KM
DENSITY = 202076. ELECTRONS/CC

VALUES FOR F1-REGION

SCALE HEIGHT = 47.56 KM
HEIGHT = 241.54 KM
DENSITY = 386989. ELECTRONS/CC

VALUES FOR F2-REGION

SCALE HEIGHT = 66.21 KM
HEIGHT = 363.07 KM
DENSITY = 1061827. ELECTRONS/CC

ELECTRON DENSITY PROFILE

KM	E-REGION	F1-REGION	F2-REGION	TOTAL	CUMULATIVE	PLASMA FREQUENCY	SCALE
100	103892.	0.	0.	103892.	8.26902699E 14	2.89	7.22
105	145409.	0.	0.	145410.	1.55395080E 15	3.42	9.45
110	177541.	2.	0.	177543.	2.44166675E 15	3.78	11.58
115	196336.	9.	0.	196345.	3.42339402E 15	3.97	13.61
120	202076.	35.	0.	202111.	4.43394876E 15	4.03	15.56
125	197431.	113.	0.	202111.	5.44450343E 15	4.03	17.43
130	185743.	323.	0.	202111.	6.45505816E 15	4.03	19.22
135	170027.	823.	0.	202111.	7.46561289E 15	4.03	20.95
140	152581.	1891.	0.	202111.	8.47616756E 15	4.03	22.61
145	134966.	3959.	0.	202111.	9.48672235E 15	4.03	24.22
150	118145.	7617.	0.	202111.	1.04972771E 16	4.03	25.77
155	102640.	13587.	0.	202111.	1.15078317E 16	4.03	27.27
160	86682.	22637.	0.	202111.	1.25183864E 16	4.03	28.72
165	76317.	35467.	0.	202111.	1.35289410E 16	4.03	30.13
170	65487.	52580.	1.	202111.	1.45394957E 16	4.03	31.49
175	56076.	74165.	2.	202111.	1.55500503E 16	4.03	32.82
180	47944.	100026.	6.	202111.	1.656060[illegible]0E 16	4.03	34.11
185	40947.	129571.	17.	202111.	1.75711598E 16	4.03	35.36
190	34943.	161856.	45.	202111.	1.85817142E 16	4.03	36.58
195	29802.	195682.	116.	225600.	1.97097120E 16	4.26	37.77
200	25407.	229716.	270.	255393.	2.09866750E 16	4.53	38.93
205	21653.	262619.	587.	284860.	2.24109748E 16	4.79	40.06
210	18450.	293160.	1203.	312812.	2.39750367E 16	5.02	41.16
215	15718.	320301.	2324.	338343.	2.56667510E 16	5.22	42.24
220	13389.	343256.	4257.	360903.	2.74712637E 16	5.39	43.29
225	11405.	361511.	7423.	380339.	2.93729565E 16	5.53	44.32
230	9713.	374821.	12360.	396895.	3.13574296E 16	5.65	45.32
235	8273.	383180.	19724.	411177.	3.34133136E 16	5.75	46.31
240	7045.	386785.	30257.	424087.	3.55337489E 16	5.84	47.27
245	6000.	385988.	44745.	436733.	3.77174148E 16	5.93	48.21
250	5110.	381252.	63962.	450323.	3.99690288E 16	6.02	49.14
255	4351.	373103.	88597.	466051.	4.22992843E 16	6.12	50.04
260	3706.	362097.	119191.	484993.	4.47242492E 16	6.25	50.93
265	3156.	348789.	156066.	508010.	4.72643012E 16	6.39	51.80
270	2687.	333709.	199283.	535679.	4.99426979E 16	6.57	52.66
275	2288.	317345.	248614.	568249.	5.27839375E 16	6.76	53.50
280	1949.	300136.	303535.	605620.	5.58120382E 16	6.98	54.32
285	1660.	282465.	363246.	647371.	5.90488905E 16	7.22	55.13
290	1413.	264658.	426710.	692781.	6.25127971E 16	7.47	55.93
295	1203.	246986.	492711.	740900.	6.62172973E 16	7.72	56.71
300	1025.	229666.	559915.	790606.	7.01703292E 16	7.98	57.48
305	873.	212871.	626942.	840686.	7.43737692E 16	8.27	58.23
310	743.	196731.	692428.	889902.	7.88232702E 16	8.46	58.98
315	633.	181338.	755088.	937059.	8.35085630E 16	8.68	59.71
320	539.	166755.	813763.	981057.	8.84138465E 16	8.88	60.43
325	459.	153019.	867458.	1020936.	9.35185266E 16	9.06	61.14
330	391.	140147.	915365.	1055903.	9.87980402E 16	9.22	61.84
335	333.	128136.	956877.	1085347.	1.04224773E 17	9.34	62.52
340	283.	116974.	991588.	1108845.	1.09768997E 17	9.45	63.20
345	241.	106635.	1019282.	1126159.	1.15399790E 17	9.52	63.87
350	206.	97087.	1039925.	1137218.	1.21085878E 17	9.57	64.53
355	175.	88295.	1053635.	1142105.	1.26796401E 17	9.59	65.18
360	149.	80217.	1060666.	1142105.	1.32506923E 17	9.59	65.82
365	127.	72812.	1061384.	1134322.	1.38178533E 17	9.55	66.45
370	108.	66035.	1056366.	1122509.	1.43791080E 17	9.50	67.07
375	92.	59845.	1046379.	1106316.	1.49322657E 17	9.43	67.68

380	78.	54199.	1032163.	1086440.	1.54754858E 17	9.35	68.29
385	67.	45056.	1014406.	1063578.	1.60072497E 17	9.25	68.89
390	57.	44377.	993735.	1038159.	1.65263341E 17	9.14	69.48
395	48.	40124.	970718.	1010891.	1.70317796E 17	9.02	70.06
400	41.	36264.	945858.	982163.	1.75228611E 17	8.89	70.64
405	35.	32761.	919599.	952395.	1.79990587E 17	8.75	71.20
410	30.	29587.	892326.	921943.	1.84600301E 17	8.61	71.77
415	25.	26711.	864375.	891112.	1.89055862E 17	8.47	72.32
420	22.	24108.	836032.	860162.	1.93356672E 17	8.32	72.87
425	18.	21753.	807539.	829311.	1.97503227E 17	8.17	73.41
430	16.	19624.	779102.	798741.	2.01496932E 17	8.02	73.94
435	13.	17699.	750889.	768602.	2.05339938E 17	7.86	74.47
440	11.	15960.	723042.	739013.	2.09035003E 17	7.71	75.00
445	10.	14390.	695674.	710073.	2.12585369E 17	7.56	75.51
450	8.	12972.	668877.	681857.	2.15994650E 17	7.41	76.02
455	7.	11692.	642723.	654421.	2.19266757E 17	7.26	76.53
460	6.	10537.	617266.	627809.	2.22405797E 17	7.11	77.03
465	5.	9495.	592548.	602048.	2.25415034E 17	6.96	77.52
470	4.	8555.	568596.	577156.	2.28301811E 17	6.81	78.01
475	4.	7708.	545431.	553142.	2.31067523E 17	6.67	78.50
480	3.	6944.	523060.	530007.	2.33717558E 17	6.53	78.98
485	3.	6755.	501488.	507746.	2.36256287E 17	6.39	79.45
490	2.	5634.	430711.	486347.	2.38688022E 17	6.26	79.92
495	2.	5075.	460721.	465797.	2.41017005E 17	6.12	80.38
500	2.	4570.	441505.	446077.	2.43247390E 17	5.99	80.84
505	1.	4116.	423050.	427167.	2.45383227E 17	5.86	81.30
510	1.	3707.	405337.	409045.	2.47428450E 17	5.74	81.75
515	1.	3338.	388347.	391686.	2.49386880E 17	5.61	82.20
520	1.	3006.	372060.	375067.	2.51262212E 17	5.49	82.64
525	1.	2707.	356453.	359161.	2.53058013E 17	5.38	83.08
530	1.	2437.	341505.	343943.	2.54777730E 17	5.26	83.51
535	1.	2194.	327192.	329387.	2.56424662E 17	5.15	83.94
540	0.	1976.	313491.	315467.	2.58001998E 17	5.04	84.36
545	0.	1779.	300379.	302159.	2.59512791E 17	4.93	84.79
550	0.	1602.	287834.	289437.	2.60959971E 17	4.8[illegible]	85.20
555	0.	1442.	275833.	277276.	2.62346351E 17	4.72	85.62
560	0.	1298.	264355.	265653.	2.63674614E 17	4.62	86.03
565	0.	1169.	253376.	254545.	2.64947340E 17	4.53	86.44
570	0.	1052.	242877.	243929.	2.66166985E 17	4.43	86.84
575	0.	948.	232837.	233784.	2.67335907E 17	4.34	87.24
580	0.	853.	223236.	224089.	2.68456349E 17	4.25	87.63
585	0.	768.	214055.	214823.	2.69530463E 17	4.16	88.03
590	0.	691.	205276.	205967.	2.70560[illegible]97E 17	4.07	88.42
595	0.	622.	196880.	197503.	2.71547809E 17	3.98	88.80
600	0.	560.	188852.	189412.	2.72494870E 17	3.90	89.18
605	0.	504.	181174.	181678.	2.73403260E 17	3.82	89.56
610	0.	454.	173830.	174285.	2.74274680E 17	3.74	89.94
615	0.	409.	166807.	167215.	2.75110757E 17	3.67	90.31
620	0.	368.	160088.	160456.	2.75913036E 17	3.59	90.68
625	0.	331.	153661.	153992.	2.76682994E 17	3.52	91.05
630	0.	298.	147511.	147809.	2.77422041E 17	3.45	91.42
635	0.	269.	141627.	141896.	2.78131518E 17	3.38	91.78
640	0.	242.	135997.	136238.	2.78812706E 17	3.31	92.14
645	0.	218.	130608.	130826.	2.79466835E 17	3.24	92.49
650	0.	196.	125450.	125646.	2.80095065E 17	3.18	92.85
655	0.	176.	120513.	120689.	2.80698509E 17	3.12	93.20
660	0.	159.	11[illegible]35.	115944.	2.81278226E 17	3.05	93.54
665	0.	143.	111[illegible]9.	111402.	2.81835234E 17	2.99	93.89
670	0.	129.	106924.	107053.	2.82370496E 17	2.93	94.23
675	0.	116.	102772.	102888.	2.82884938E 17	2.88	94.57

680	0.	104.	98795.	98900.	2.83379433E 17	2.82	94.91
685	0.	94.	94985.	95079.	2.83854827E 17	2.77	95.25
690	0.	84.	91334.	91419.	2.84311917E 17	2.71	95.58
695	0.	76.	87835.	87911.	2.84751475E 17	2.66	95.91
700	0.	68.	84482.	84550.	2.85174227E 17	2.61	96.24
705	0.	62.	81267.	81329.	2.85580871E 17	2.56	96.56
710	0.	55.	78186.	78241.	2.85972077E 17	2.51	96.89
715	0.	50.	75230.	75280.	2.86348477E 17	2.46	97.21
720	0.	45.	72396.	72441.	2.86710683E 17	2.41	97.53
725	0.	40.	69678.	69719.	2.87059274E 17	2.37	97.84
730	0.	36.	67070.	67107.	2.87394807E 17	2.32	98.16
735	0.	33.	64569.	64601.	2.87717813E 17	2.28	98.47
740	0.	30.	62168.	62197.	2.88028798E 17	2.24	98.78
745	0.	27.	59864.	59891.	2.88328251E 17	2.20	99.09
750	0.	24.	57653.	57677.	2.88616630E 17	2.15	99.39
755	0.	22.	55530.	55551.	2.88894388E 17	2.11	99.70
760	0.	19.	53491.	53511.	2.89161938E 17	2.07	100.00
765	0.	17.	51534.	51552.	2.89419696E 17	2.04	100.30
770	0.	16.	49655.	49670.	2.89668044E 17	2.00	100.60
775	0.	14.	47849.	47863.	2.89907360E 17	1.96	100.89
780	0.	13.	46115.	46127.	2.90137994E 17	1.93	101.19
785	0.	11.	44448.	44460.	2.90360290E 17	1.89	101.48
790	0.	10.	42847.	42857.	2.90574574E 17	1.86	101.77
795	0.	9.	41308.	41317.	2.90781158E 17	1.82	102.06
800	0.	8.	39829.	39837.	2.90980342E 17	1.79	102.34
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810	0.	7.	37039.	37046.	2.91357636E 17	1.73	102.91
815	0.	6.	35725.	35731.	2.91536289E 17	1.70	103.19
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845	0.	3.	28825.	28828.	2.92483512E 17	1.52	104.85
850	0.	3.	27822.	27825.	2.92622632E 17	1.50	105.12
855	0.	3.	26857.	26859.	2.92756927E 17	1.47	105.39
860	0.	2.	25927.	25930.	2.92886576E 17	1.44	105.65
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875	0.	2.	23342.	23343.	2.93249330E 17	1.37	106.44
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885	0.	1.	21773.	21775.	2.93470919E 17	1.32	106.96
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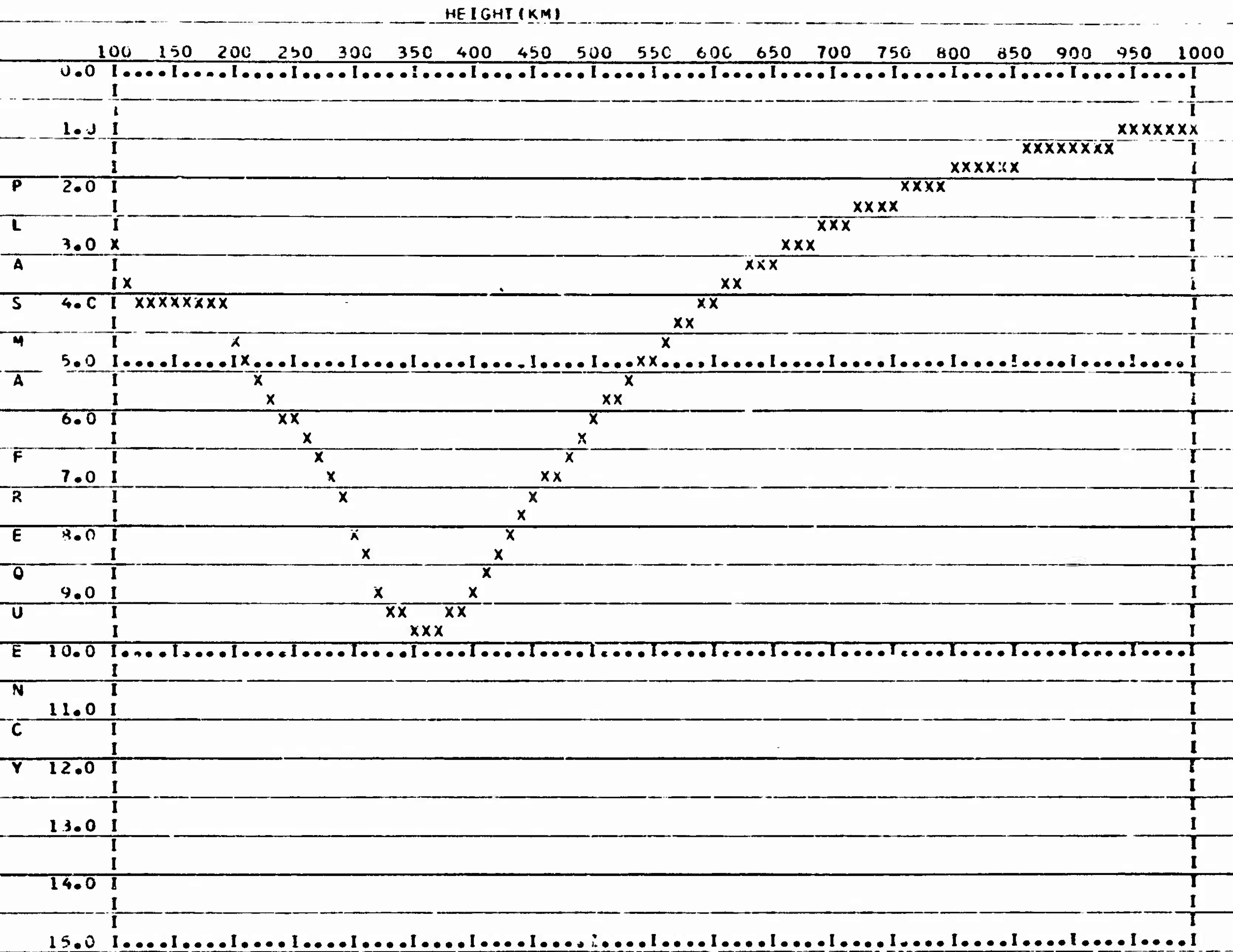
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P L A S M A F R E Q U E N C Y

IONOSPHERIC PROFILE VALID 23 MAY 70 - 07 JUN 70 1830Z TO 1930Z

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13. ABSTRACT

This paper describes a project undertaken by 4th Weather Wing to produce a realistic electron density profile based upon parameters which can be forecast with reasonable accuracy. The ionospheric electron density profile model presented in this paper consists of the sum of three Chapman layers (E, F1, F2). Electron densities in the topside ionosphere are controlled by complex motions rather than a production-loss balance and cannot be successfully described strictly by a Chapman layer. After some experimentation a best fit was obtained by simply using the Chapman equation for the topside ionosphere, but computing the electron densities by using a variable scale height throughout the region. The program described in this report has been used routinely for eight months to predict profiles for radar refraction. This report should be considered interim as improvements in accuracy are sure to be required as the model is evaluated for different purposes.